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# Energy audit and prospective energy conservation at residential college buildings in a tropical region

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**Abstract**

Twelve residential colleges located at the capital city of Kuala Lumpur were selected for an energy audit to evaluate the performance of electricity use according to the Energy Efficiency Index (EEI). The residential colleges that had special features of building layout and arrangement, such as courtyards and balconies, performed better with regard to electricity consumption compared to the buildings with a linear arrangement, due to the prior group's superior utilization of day lighting and natural ventilation. In addition, the floor area of the rooms, the volume, density, enclosural and facade design including window design, area, window to wall ratio etc. also influenced the total electricity usage of the residential college buildings. The fluorescent lighting and fans are two major contributors to total electricity usage, and with an adaptation of the corridor area to include more natural ventilation and day light, the electricity consumption can be markedly reduced. As a result, it was shown that approximately 40 to 80% of average electricity usage could be conserved in a year, while at the same time improving the indoor environmental quality.

*Keywords:* Building Energy Performance-BEP, climate change, energy audit, energy conservation, Energy Efficiency Index-EEI, residential college.

## 1. Introduction

The increase of greenhouse gases (GHGs) in the atmosphere is mostly caused by human activities that include combustion activities to generate energy from fossil fuels [1]. The increasing amount of GHGs causes global warming, which directly leads to the climate change phenomenon. The changes in climate, again, directly lead to an increase in the demand of energy. As presented by the United Nation Environment Programme (UNEP), and the United Nations Framework Convention on Climate Change (UNFCCC) [2], at mid and high latitudes and altitudes there will be a decline in heating requirements, but the cooling requirements will increase.

Recently, Isaac and vanVuuren [3] found that the climate change results in decreases in global heating demands by over 30%, but at the same time it causes increases in cooling demand of about 70%, thus influencing the increase in energy demand for residential air conditioning in South Asia by about 50%. Consequently, energy supply systems will be vulnerable as the situation worsens, as intensifying water deficits lead to less winter snowfall to fill up summer streams, and the higher demand for freshwater will also affect hydropower production.

The building sector has been identified as a major energy consumer since nearly half of the world's energy use is associated with providing environmental conditioning in buildings, and about two thirds of this energy are used for heating, cooling and mechanical ventilation [4]. According to Ryghaug and Sørensen [5], the building sector represents approximately 40% of onshore energy usage. From a local perspective, residential consumption was stated as the third highest energy consumption after industrial and commercial one. [6] According to the Economic Planning Unit, Prime Minister's Department [7], the average annual growth rate for residential and commercial energy consumption is expected to go up by 0.4% from 5.6% in the 8$^{th}$ Malaysian Plan period to 6.0% in the 9$^{th}$ Malaysian Period (2006-2010). Thus, energy conservation in the building sector should be acknowledged as a holistic approach to reducing the emission of greenhouse gases. The stabilization of building- related $CO_2$ emission levels for 2004-2030 will help to prevent the predicted temperature increase of approximately 3°C [8].

The evaluation of consumption patterns and the identification of specific energy saving measures are the most important parts of the energy management activities, which include energy conservation programmes, and can be achieved via energy audits [9]. With regards to different levels of sophistication, energy audits can be divided into two types: a walkthrough audit, which includes a simple study of some of the major equipment and systems, and a detailed audit, which entails a thorough study of practically all equipment and systems [10]. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) [11] stated three different levels of analysis for energy audits as listed below:

- Preliminary energy use analysis
  The building's energy consumption is evaluated by developing an Energy Use Intensity (EUI) resulting from existing annual utility billing.

- Level I analysis - Walkthrough analysis
  A visual inspection of the building's mechanical and electrical systems through interviews of the building operating personnel and evaluation of non-energy related capital investments.

- Level II analysis – Energy survey and analysis

More detailed building survey and expanding on the walk-through analysis by conducting field measurements while energy saving and cost analysis are also completed.

- Level III analysis – Detailed analysis of capital-intensive modifications
  Built on the dynamic energy model of existing systems by using software to understand the return on investment of each option; also known as investment grade audit.

From studying the existing literature, few studies have been conducted on multi-residential buildings, especially in tropical regions. Most of the reported studies have focussed on residential housing, which includes single storey, double storey, flat houses and apartments [12, 13, 14, 15], which are quite different in terms of building layouts and services provided. The multi-residential building typically plays a role as student halls of residence, key worker accommodation, care homes and sheltered houses, typically containing catering facilities, lounges, dining rooms, health and leisure areas, offices, meeting rooms and other support areas such as laundry facilities [16]. In Malaysia, the multi-residential building, which provides accommodation to university students, is also referred to as residential college or hostel.

According to the Ministry of Higher Education [17], there are 20 public universities, and 525 private universities, in Malaysia; this number includes branch campuses for overseas' universities, colleges, and university colleges, as well as 27 polytechnics and 59 community colleges, which offer various programmes from certificate to higher degree level, in Malaysia. As recorded by the Planning and Research Unit [18] in the Malaysia Higher Education Statistic for 2008, there were 369,169 students, with 921,548 of students enrolled in all higher education institutions. These figures show the growth from year to year, when six years back, in 2003, there was a student intake of only approximately 262,626 students. This also indicates the number of accommodation facilities that need to be provided for the students. Thus, the implementation of energy conservation strategies at residential colleges is anticipated to be very useful in reducing the overall electricity usage, and this should start with an energy audit.

The aims of the study were to evaluate the efficiency of electricity use of twelve residential colleges and to estimate the potential of reducing electricity usage. This was achieved by multiplying the average energy use of a residential building in Malaysia (25kWh/m$^2$/year) with the total floor area (TFA) of each residential college and then calculating the energy usage by the basic electrical appliances of the buildings necessary to run their basic services.

## 2. Research design and approaches

### *2.1. Building description*

Twelve residential colleges were chosen in this study. They are located within the University of Malaya campus, namely: Tunku Abdul Rahman Residential College (R1), Tuanku Bahiyah Residential College (R2), Tunku Kurshiah Residential College (R3), Bestari Residential College (R4), Dayasari Residential College (R5), Ibnu Sina Residential College (R6), Za'ba Residential College (R7), Kinabalu Residential College (R8), Tun Syed Zahiruddin Residential College (R9), Tun Ahmad Zaidi Residential College (R10), Ungku Aziz Residential College (R11) and Raja Nazrin Shah Residential College (R12). This campus is located in the capital city of Kuala Lumpur, Malaysia, and provides residences to more than 11,000 students, including local and international students. Eight out of the twelve residential colleges consist of one administrative building and four to six multi-residential buildings, while another four have allocated their administrative offices to the lower ground of the multi-residential buildings. All the administrative offices are equipped with air-condition, while all the rooms in the twelve multi-residential buildings are non-air conditioned and are only provided with a ceiling fan and a fluorescent lamp. At all colleges, the dining hall, student activity centre, prayer room, multipurpose hall and other facilities are located in the administrative building. Background information of each residential college building is shown in Table 1.

**Table 1**
Background information of the twelve residential colleges

### *2.2. Performance of electric use*

The efficiency of electricity use in each of the residential colleges was evaluated by adapting a method from Saidur [6], who estimated energy intensity, EI, in kWh/$m^2$ by using the following equation:

$$EI = AEC / TFA$$

where AEC is annual energy consumption (kWh), while TFA is total floor area ($m^2$). Basically, Kamaruzzaman and Edwards [19] stated that the energy use per unit floor area can be described as 'Normalised Performance Indicators' (NPI), which is also known as the energy use index or Building Energy Performance (BEP) [10]. In addition, if the energy use is in Mega Joule (MJ) per unit floor area, it will be noted as Energy Utilization Index (EUI). Consequently, the term BEP will be used in this study to indicate the performance of electric use at residential colleges, while Energy Efficiency Index (EEI) will be used to elaborate the kWh/$m^2$/year [20, 21].

Referring to Iwaro and Mwasha [22], energy use in residential buildings is usually 10 to 20 times lower compared to office buildings. Thus, the total electricity usage in residential buildings in Malaysia amounts to 10 to 25 kWh/m$^2$/year if the electricity use in office buildings in Malaysia is in the range of 200 to 250 kWh/m2/year [23].

The energy consumption data were collected and analyzed for a five years period, beginning from 2005 until 2009, while total floor area was calculated from the building design study. On-site measurements were also carried out for the purpose of obtaining accurate facts, since errors arose from sources such as outdated drawings and recent renovations. Further statistical analysis was carried out using SPSS 15.0 (Standard version) computer software package. Descriptive statistical analysis was performed to analyze mean, median, mode, standard deviation, variance and range for comparison purposes.

### *2.3. Estimation of electricity savings*

The total savings of electricity in residential colleges were identified through the difference between average total energy use in a year (kWh) and minimum electricity usage by the residential college using two different calculations. First, the maximum amount of units of average electricity usage at residential buildings in Malaysia, which are in the range of 10 to 25kWh/m$^2$/year, was multiplied with the TFA of each residential college building. Thus, the minimum electricity usage of a residential college on the current average of local consumption or requirement was identified.

Next, the minimum electricity usage was calculated for the basic electrical appliances of each sector: rooms, office, dining hall etc., for the residential college as running the basic services in providing minimal comfort to the residents. The mechanical and electrical (M&E) inventory was conducted using data supplied by the administrator of the residential colleges and gathered by a walk-through survey for verification purposes. These two techniques are suitable for energy studies and essential for technology review systems [24]. As a consequence, the precise figure of the minimum electricity usage was directly determined.

## 3. Results and discussion

**Table 2**
The electricity consumption at twelve residential colleges

The electricity consumption, particularly the monthly and annual usage (kWh), Building Energy Performance - BEP (kWh/m$^2$) and Energy Efficiency Index - EEI (kWh/m$^2$/year) of twelve residential colleges for five years duration from 2005 to 2009 are presented in Table 2.

Generally, four residential colleges, namely R1, R4, R5 and R6, accrued the highest range values of BEP, as well as monthly usage values, exceeding three times the mean values due to their extremely high electricity usage during certain months. Thus, the mean values for the performance of electricity consumption were far-off from the normal value or regular usage of electricity and did not actually represent the monthly electricity consumption in an appropriate manner. Unfortunately, these situations do not occur in annual performances when the range values of all residential colleges are not really considerable, except for R1 and R5, where the range values were nearly equal to the mean values stated by both residential colleges. As a consequence, median values were used for the comparison of electricity consumption performance among these twelve residential colleges.

Through EEI ranking, R5 leads the list with the lowest electricity consumption of 23.909 kWh/m$^2$/year, while R3 ranked last in the list due to the highest electricity consumption, exceeding 124.940 kWh/m$^2$/year. The ranking of the EEI values in the other residential colleges was in the following order: R5>R11>R12>R6>R9>R10>R1>R4>R7> R2>R8>R3. The same order was also found in the BEP ranking, except for the first and second places, where R5 (2.268 kWh/m$^2$) and R11 (2.0 kWh/m$^2$) swap places, while R3 still remains the largest user of electricity, at 10.412 kWh/m$^2$.

Referring to both rankings, the EEI and BEP, the residential colleges with different features of building layout and arrangement, such as R5 - courtyard arrangement, R11 - courtyard arrangement with balconies and R12 - linear arrangement with balconies, are leading the list on reduced electricity use, whilst most buildings with a linear arrangement show a higher electricity consumption. This situation is attributed to their need of having fluorescent lamps switched on continuously in corridors and staircases, even during day time. This issue has been identified at R1, R2, R3, R4, R6, R7, R8, and to a certain level at R10. Open corridors in the centre of the buildings at each level allow day light to penetrate into the building, which has placed R9 at fifth rank. As an improvement, the increase of both window to wall ratio (WWR) and operable window to wall ratio at R9, which is the smallest among the residential colleges, is expected to significantly reduce the electricity consumption from lighting inside the rooms, as is demonstrated by R5, which was designed with the biggest WWR. Small WWR of a room will force residents to switch on the light even during day time for sustaining their visual comfort [25]. In contrast to this, R5 and R11, which are based on a courtyard arrangement, do not require the

fluorescent lamps in the corridor and staircase area to be switched on during day time. The wing walls on the top of the entrance door and wall of each room at R5 fully function in providing air circulation and day light inside the room. The existence of a balcony at each room of R11 and R12 helps to enhance natural ventilation and day lighting, while at the same time allowing the residents to control the level of thermal and visual comfort in a natural way.

In addition, the window design also influences the electricity consumption in terms of cooling [26]. The centre pivot and awning window at R5, and the casement and turn window at R11, indirectly help the residents to channel the wind into the room, although the opening locations do not correspond to the wind direction. Furthermore, with the biggest room area (20.0m$^2$) and volume (57.4m$^2$) at R11, the indoor air circulation is drastically increased. Thus, natural ventilation can be fully optimized and directly reduces the cooling load for the buildings [27].

In contrast to this at R3, with the highest population density of 0.107 per m$^2$, compared to other residential colleges which range from 0.026 to 0.064 per m$^2$, the building design hinders the optimization of day light and natural ventilation, even though this building includes the biggest operable window area (5.76m$^2$) and operable window to wall ratio (0.53). The same situation is also encountered at R4 and R8, where the building's opening to the wind direction denies the optimization of day light and natural ventilation, particularly in the corridor area.

Looking at the landscape perspective, the contributions of green area to reducing energy consumption through the reduction of the buildings' cooling load are not really significant. Referring to R2 and R3, they have more than 75% of green area, but are listed in the last placement in the EEI ranking due to a higher population density unit, which is more than 0.050 compared to the other residential colleges.

When comparing the EEIs of each residential college to the current average for electricity usage in residential buildings in Malaysia, only R5 and R11 are in the range of 10 to 25 kWh/m$^2$/year. This is due to the presence of air conditions at the administrative offices of the residential colleges, which directly increase the electricity consumption on a whole.

**Table 3**
The calculation of minimum electricity usage at the residential colleges

With regards to the second method of calculating the minimum electricity usage of the residential colleges, first all basic M&E equipment is listed, according to the building and area as shown in Table 3. The

fluorescent lights and fans were identified as two of the major basic M&E appliances at the residential colleges, and the wattage of each appliance was adapted from Saidur et al [28]. The usage duration of each M&E unit were calculated considering the main student activities, which include attending lectures and classes at the faculties during day time and other activities during the weekends. For the administrative offices, the usage duration was assumed only for working hours during weekdays, while other areas were calculated based on regular usage by the residents and staff as well as services offered. The number of M&E units from the inventory list supplied by the administration and walk-through survey was multiplied with energy used in kWh unit for a year, as listed in the last column of Table 3. Thus, the minimum annual electricity usage of each residential college was derived from the sum of annual usage by all basic M&E appliances.

**Table 4**
The potential of electricity saving at the twelve residential colleges

The sums potential of electricity saving at the twelve residential colleges, which were estimated by calculating the difference between average total energy use in a year (kWh) and minimum electricity usage, by multiplication of TFA with 25kWh/m$^2$/year and basic M&E inventory, are presented in Table 4. The first calculation revealed that R11 demonstrated a negative percentage of electricity saving potential, due to it already having achieved a mean EEI in the range of 10 to 25kWh/m$^2$/year.

By taking both first and second calculations into consideration, electricity use at the residential colleges could be reduced by about 40 to 80% annually. R3, which was identified as the highest annual user of electricity, also possesses the highest potential for electricity saving of more than 70%, followed by R4 with more than 60%. Although ranked as the lowest electricity consumer among the twelve residential colleges with 24.235kWh/m$^2$/year, there is still a big potential for electricity saving at R11, exceeding 55.45%, as a result of the calculations of the basic M&E inventory list. Higher percentages of electricity saving potential are also deduced from the calculations of the basic M&E inventory lists at the colleges R4, R5, R6, R9, R10 and R12. In contrast, the colleges R1, R2, R3, R7 and R8 reveal a much lower percentage potential of electricity saving, which indirectly indicates that much of the basic M&E appliances are fixed in sustaining the residents' thermal or visual comfort levels.

From the walk through investigation, it was seen that the electricity wastage usually occurs in the corridor and staircase areas, especially at residential colleges with linear arrangement and layout, where the fluorescent lamps need to be switched on even during day time. As a consequence, with improved management

of the building services by the administration and with the full support from the residents, approximately 10 to 40% of average electricity usage could easily be conserved in the short term yearly plan.

## 4. Conclusions

The average electricity usage of non air-conditioned residential colleges in tropical regions, such as in Kuala Lumpur, are in the range of 20 to 60 kWh/m$^2$/year. Especially the fluorescent lights and the fans are identified as two major M&E electricity consumers at the residential colleges. The presence of a courtyard and balconies in the residential college arrangement reduces the overall electricity consumption, as it allows for full utilization of day light and natural ventilation. Specifically, enclosural and facade design, including window design, area and ratio to wall area, contribute a significant effect, while the population density should also be critically considered. A higher population density will obstruct the effectiveness of energy conservation approaches and indirectly reduce the residents' comfort levels. The possibility of natural ventilation and day light to reach the corridor area will have a significant impact on the overall electricity consumption, since corridor fluorescent lighting has been identified as the biggest contributor to electricity wastage, particularly at the residential colleges with a linear arrangement. From a holistic view, about 40 to 80% of average electricity usage could be conserved in a year, while at the same time improving the quality of the indoor environment.

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